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Research Article

Leaf Area, Fresh Weight and Dry Weight Prediction Models for Ornamental Plants *Ficus benjamina* (cv. Starlight)

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Abstract: Measurements of leaf growth indices namely leaf area, fresh weight and dry weight are of value in physiological studies and plant growth estimation. The use of prediction models to estimate leaf area, fresh weight and dry weight is simple, rapid and nondestructive. Several mathematical functions have been formulated for estimating leaf area, fresh weight and dry weight of various crops but almost there is no information for *Ficus benjamina*. This work was aimed to propose leaf area (*LA*), fresh weight (*FW*) and dry weight (*DW*) prediction models for *Ficus benjamina* (cv. Starlight) leafy ornamental pot plant using leaf length (*L*) and width (*W*). 1000 leaves were collected randomly from greenhouse grown plants and 700 of cuts were used for prediction models. *LA* was measured with a digital area meter (DELTA-T, Co. Durham, UK), related *FW* and *DW* also were weighted and leaf dimensions were determined by the ruler. For each studying growth index *LA*, *FW* and *DW* the predictive abilities of three regression equations (linear, polynomial and power) were compared with different independent variables for each equation. Leaf length × width provided a good estimation of leaf area and fresh weight of the leaves of *Ficus benjamina*. It was also concluded that leaves the dry weight of *Ficus benjamina* can be estimated or simulated as a power function of $L \times W$ or $L+W$ with reasonable accuracy. Moreover, a reasonable relationship between leaf fresh weight and leaf area was found too.

Keywords: Foliage pot plants, Leaf area estimation, Leaf growth estimation, Non-destructive methods, *Ficus benjamina.*

1. Introduction

Leaf growth indices including leaf area (*LA*), leaf fresh weight (*FW*), and leaf dry weight (*DW*) are important factors required in most physiological and agronomic studies involving plant growth (Guo and Sun, 2001). *LA* has a remarkable effect on growth and its estimation is a key component of crop growth models (Lizaso *et al*., 2003; Rouphael *et al*., 2006). Different methods to measure leaf area (Evans, 1972; Causton & Venus, 1981; Norman & Campbell, 1991; Bignami and Rossini, 1996) are time-consuming, destructive and the facilities are commonly expensive. Therefore, it is of value to find a non-destructive and repeatable method during the growth period which is inexpensive and reduces the experimental variability associated to destructive sampling procedures (NeSmith, 1992; De Swart *et al*., 2004). Several prediction models have been determined to estimate leaf area for numerous horticultural crops (Potdar and Pawar, 1991; Montero *et al*., 2000; Stoppani *et al*., 2003; Demirsoy *et al*., 2004; De Swart *et al*., 2004; Salerno *et al*., 2005; Rouphael *et al*., 2006; Serdar and Demirsoy, 2006; Cho *et al*., 2007; Cristofori *et al*., 2007; Mendoza-de Gyves *et al*., 2007; Peksen, 2007; Rivera *et al*., 2007; Tsialtas *et al*., 2008; Olfati *et al*., 2009; Rouphael *et al*., 2010). In a number of research works, there is a strong relationship between *L* and *W* and *LA*, *FW* and *DW* (Mokhtarpour *et al*., 2010) or *DW* (Karimi *et al*., 2010) appeared to be reasonably related to leaf area. While information on the estimation of ornamental plant, *LA*, *FW* and *DW*, especially *Ficus benjamina* is still deficient. The objective of this study was focused to develop non-destructive models for estimating *LA*, *FW* and *DW* of *Ficus benjamina*, based on leaf length and width.

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2. Materials and Methods

2.1 Model construction

The experiment was conducted in north of Iran (Gorgan; Latitude: N 37°00' to 37°30' and Longitude: E 54°00' to 54°30'). The eco-climate of Gorgan is moderate and humid. The present investigation was carried out on small pot plants raised from semi hardwood cuttings transplanted in 4 liter plastic pots containing 22 different pot mixtures in glass-house conditions. Sampling was done at 9 months after beginning of growth in spring and a total of 1000 leaves harvested for this experiment. The length from the lamina tip to the intersection of the lamina and petiole along the lamina midrib and the maximum width of all leaves were measured manually with a simple ruler to the nearest 1.0mm (Fig. 1). The leaf area measured with a digital leaf area meter (DELTA-T, Co. Durham, UK) to the nearest 1.0cm^2. Fresh weight of each leaf also was measured and then dry weights were determined after drying in 70°C oven for 48 hours. The fresh and dry weight of leaves was measured to the nearest 0.001g. The relationships between *LA*, *FW* and *DW* as a dependent variable and length (L), width (W), $L+W$, $L\times W$, L^2 and W^2 as independent variables and also *LA* as dependent variable and *FW* and *DW* as independent variable were determined using regression analysis on a total data of 700 leaves. Coefficients of determination (R^2) were calculated and equations with the highest R^2 were used in the final estimations. The linear, polynomial and power functions were developed through SAS software (SAS Institute, 1992) and Excel worksheet.

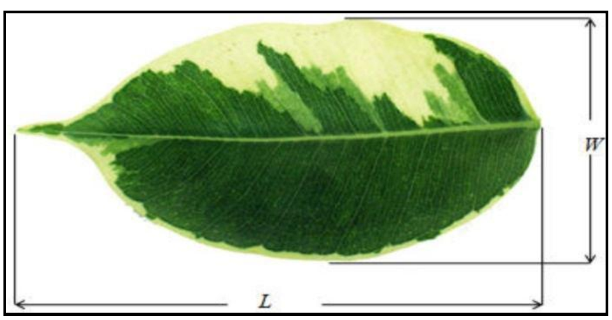

Fig. 1. *Ficus benjamina* leaves showing the point of leaf length (*L*) and width (*W*) measurement.

The estimated *LA*, *FW*, and *DW* were determined by fitting the equations. Then estimated and measured *LA*, *FW* and *DW* were compared with testing the significance of regression equation and degree of goodness of fit R^2 between estimated and observed values. The model with lower root mean square error (RMSE), lower relative mean absolute error (RMAE), higher R^2, lower bias of the linear regressed line between observed versus predicted values from the 1:1 line and lower coefficient of variance (CV) was selected as the best model to estimate leaf area by following formulas.

$$\text{Bias} = \frac{1}{N}\sum_{i=1}^{N} D_i \qquad (1)$$

$$RMSE = \sqrt{\frac{1}{N}}\sum_{i=1}^{N}(D_i)^2 \qquad (2)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(D_i)^2} \qquad (3)$$

$$CV = \frac{RMSE}{\bar{Y}} \times 100 \qquad (4)$$

Where, N is the total number of situations, Y_i and $\hat{Y}$ are the observed and predicted Y values, respectively, and $D_i = Y_i - \hat{Y}$ (Wallach, 2006).

'*a*' and '*b*' (as intercept and slope values of linear regression between observed versus predicted values of leaf area) were compared with zero and 1. A closer '*a*' to zero and closer '*b*' to 1 indicate better estimates of models.

2.2 Model validation

In order to validate the selected models for estimating *LA*, *FW* and *DW* about 300 leaves were randomly sampled and *LA*, *L* and *W* were determined by the previously described procedures. These values were used as independent data to validate the models (were not used in model fitting). The slope and intercept of the model were tested to see if they were significantly different from the slope and intercept of the 1:1 correspondence line. Regression analyses were conducted using SAS software (SAS Institute, 1992).

3. Result

Various mathematical models for indirect estimation of leaf area and lesser leaf fresh weight and leaf dry weight of different plant species have been described. The outcomes of the present study were in agreement with some of the previous studies mentioned above on non-destructive model development for predicting leaf area, leaf fresh weight and leaf dry weight using simple linear leaf measurements. Different prediction equations obtained for estimating the *LA*, *FW* and *DW* of *Ficus benjamina* (cv. Starlight) involving different independent variables, viz, L, W, L^2, W^2, $L+W$ and $L\times W$ were formulated for estimating leaf area by using different equations. The equations with lower R^2 and higher *CV* were eliminated at the beginning of this study (Fig. 2).

However, for estimating *LA* by L and W, linear and polynomial functions using a product of L and W viz., Eq. (6) and (5) [$Y = a + b(L\times W) + c(L\times W)^2$ and $Y = a + b(L\times W)$ respectively] had a higher R^2 value (0.950 and 0.949) with a lower bias (-0.0004 and -0.0005), lower RMSE (0.74 and 0.75), lower RMAE (0.090 and 0.092) and lower *CV* (10.20% and 10.30%) than other equations tested and showed the best *LA* estimation (Table 1, Fig. 2: no. 1 and 2). Evaluation of these two models by 300 data from independent leaf length and width measurements showed that both models are efficient to estimate *LA* (Table 2, Fig. 3: no. 1 and 2).

For fresh weight, power function viz., Eq. (4) Using the product of length and width described the good relationship which had approximately higher R^2 value (0.838), lower bias (0.002), lowest RMSE (0.029), lowest RMAE (0.137) and lower *CV* (16.94%) than other equations tested and showed the best *FW* estimation (Table 3, Fig. 2: no. 3). Evaluation of this model by 300 data from independent leaf length and width measurements showed that this model is practical to estimate *FW* (Table 4, Fig. 3: no. 3).

Using the same method as in *LA* and *FW* for estimating dry weight by measuring length and width, power functions viz., Eq. (4) and (3) using correspondingly product and sum of leaf length and width showed the highest R^2 value (0.771 and 0.761), nearly lower bias (0.0007 and -0.0014), lowest RMSE among the other models to estimate *DW* (Table 5, Fig. 2: no. 4 and 5). Validation of these two models by 300 data from independent leaf length and width measurements showed that both models are appropriate to estimate *FW* (Table 6, Fig. 3: no. 4 and 5).

Table 1. Slope (b) and intercept (a) values of the models used to estimate the *Ficus benjamina* (cv. Starlight) leaf area (*LA*) of single leaves from length (*L*) and width (*W*) measurements.

Model number	Regression model	R^2	Bias	RMSE	RMAE	*CV*	*a*	*b*
1	$LA = 0.3248L^2 - 0.5838L - 1.0012$	0.886	-0.00100	1.120	0.140	15.38	0.829	0.896
2	$LA = 0.8983W^{2.1271}$	0.903	0.06900	1.050	0.119	14.45	0.591	0.909
3	$LA = 1.078W^2 - 0.0255W - 0.2526$	0.900	0.00060	1.050	0.120	14.40	0.726	0.900
4	$LA = 0.1562(L+W)^2 - 0.4731(L+W) - 0.9684$	0.941	0.00030	0.810	0.101	11.07	0.429	0.941
5	$LA = 0.573(L\times W) - 0.8412$	0.949	-0.00050	0.750	0.092	10.30	0.371	0.949
6	$LA = 0.0025(L\times W)^2 + 0.4956(L\times W) - 0.3263$	0.950	-0.00040	0.740	0.090	10.20	0.364	0.950
7	$LA = 0.2703(L^2) - 0.4971$	0.886	-0.00110	1.124	0.138	15.41	0.886	0.833
8	$LA = 0.0006(L2)2 + 0.2331(L^2) - 0.0065$	0.887	-0.01100	1.120	0.140	15.37	0.821	0.889
9	$LA = 0.8983(W^2)^{1.0635}$	0.903	0.07000	1.054	0.119	14.46	0.591	0.909
10	$LA = -0.0011(W^2)^2 + 1.0902(W^2) - 0.341$	0.900	0.00040	1.049	0.120	14.40	0.726	0.900
11	$LA = 1.0732(W^2) - 0.2848$	0.900	-0.00007	1.050	0.120	14.40	0.726	0.900

Table 2. Validation of models for estimation of total leaf area of *Ficus benjamina* cuttings.

Model number	R^2	Bias	RMSE	RMAE	*CV*	*a*	*b*
1	0.893	-0.124	0.891	0.130	13.73	0.798	0.896
2	0.810	-0.037	1.215	0.154	18.72	0.602	0.913
3	0.810	-0.118	1.217	0.154	18.74	0.721	0.907
4	0.921	-0.079	0.767	0.106	11.81	0.409	0.949
5	0.913	-0.089	0.814	0.106	12.55	0.325	0.964
6	0.914	-0.077	0.804	0.106	12.38	0.349	0.958
7	0.891	-0.138	0.901	0.129	13.88	0.781	0.901
8	0.893	-0.132	0.892	0.130	13.75	0.800	0.897
9	0.810	-0.037	1.215	0.154	18.72	0.602	0.913
10	0.810	-0.119	1.218	0.154	18.76	0.717	0.908
11	0.810	-0.119	1.217	0.154	18.74	0.721	0.907

Table 3. Slope (b) and intercept (a) values of the models used to estimate the *Ficus benjamina* (cv. Starlight) leaf fresh weight (*FW*) of single leaves from length (*L*) and width (*W*) measurements.

Model number	Regression model	R^2	Bias	RMSE	RMAE	*CV*	*a*	*b*
1	$FW = 0.0067L^{1.8617}$	0.762	0.004	0.034	0.164	20.10	0.044	0.714
2	$FW = 0.0246W^{1.8779}$	0.810	0.003	0.031	0.144	18.15	0.035	0.778
3	$FW = 0.0025(L+W)^{1.9813}$	0.824	0.001	0.030	0.144	17.51	0.035	0.791
4	$FW = 0.0109(L\times W)^{0.997}$	0.838	0.002	0.029	0.137	16.94	0.032	0.803
5	$FW = 0.0067(L^2)^{0.9308}$	0.762	0.004	0.034	0.164	20.10	0.044	0.714
6	$FW = 0.0246(W^2)^{0.9389}$	0.810	0.003	0.031	0.144	18.15	0.035	0.778

FW, leaf fresh weight; *L*, leaf length; *W*, leaf width

Table 4. Validation of models for estimation of total leaf area of *Ficus benjamina* cuttings.

Model number	R^2	Bias	RMSE	RMAE	*CV*	*a*	*b*
1	0.718	0.006	0.028	0.148	18.76	0.036	0.719
2	0.736	0.006	0.028	0.134	18.50	0.020	0.828
3	0.779	0.005	0.025	0.126	16.57	0.024	0.806
4	0.790	0.006	0.024	0.123	16.37	0.020	0.825
5	0.718	0.006	0.028	0.148	18.76	0.036	0.719
6	0.736	0.006	0.028	0.134	18.50	0.020	0.828

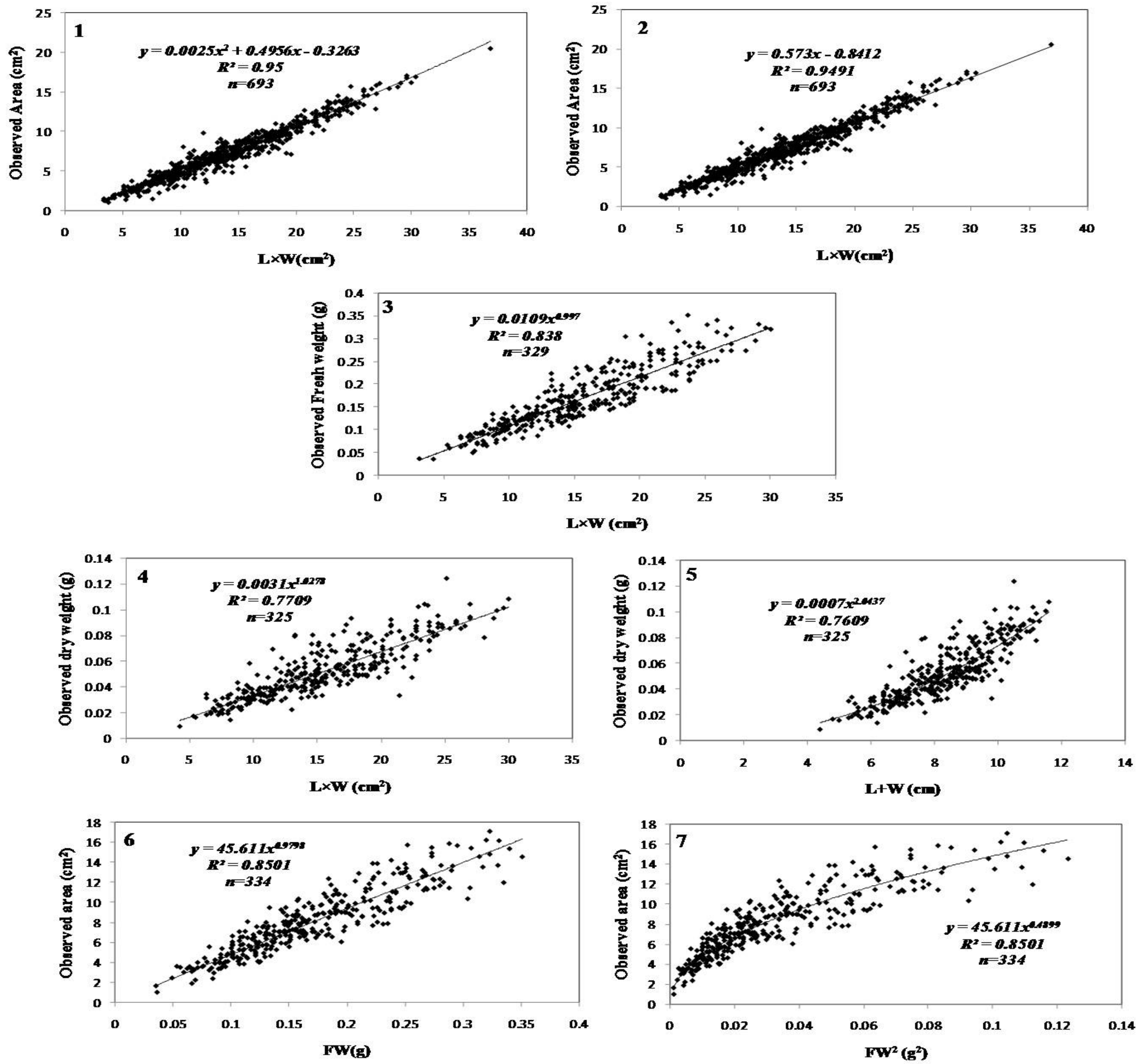

Fig. 2. Selected regression models for estimating the leaf area, fresh and dry weight of *Ficus benjamina* from the leaf length by width product (*L×W*) and sum (*L+W*) and also estimating the leaf area from fresh weight.

Table 5. Slope (b) and intercept (a) values of the models used to estimate the *Ficus benjamina* (cv. Starlight) leaf dry weight (*DW*) of single leaves from length (*L*) and width (*W*) measurements.

Model number	Regression model	R^2	Bias	RMSE	RMAE	*CV*	*a*	*b*
1	$DW = 0.0019L^{1.9176}$	0.7057	0.0008	0.0120	0.188	22.69	0.063	0.6761
2	$DW = 0.0065W^2 - 0.0002W + 0.0031$	0.7172	0.0001	0.0113	0.178	21.26	0.0179	0.666
3	$DW = 0.0007(L+W)^{2.0437}$	0.7609	-0.0014	0.011	0.177	20.83	0.0159	0.6578
4	$DW = 0.0031(L\times W)^{1.0278}$	0.7709	0.0007	0.0107	0.158	20.22	0.0168	0.6786
5	$DW = 0.0001(W^2)^2 + 0.004(W^2) + 0.0144$	0.736	0.0014	0.0114	0.170	21.43	0.6266	0.0189
6	$DW = 0.0019(L^2)^{0.9588}$	0.7057	0.0008	0.0120	0.188	22.69	0.0187	0.6421

DW, leaf dry weight; *L*, leaf length; *W*, leaf width

Table 6. Validation of models for estimation of total leaf area of *Ficus benjamina* cuttings.

Model number	R^2	Bias	RMSE	RMAE	*CV*	*a*	*b*
1	0.737	0.0019	0.008	0.130	17.52	0.008	0.782
2	0.745	0.0012	0.008	0.126	17.59	0.004	0.876
3	0.795	0.0006	0.007	0.118	15.44	0.004	0.895
4	0.810	0.0024	0.007	0.119	15.86	0.006	0.906
5	0.746	0.0025	0.008	0.133	18.19	0.003	0.877
6	0.737	0.0019	0.008	0.130	17.52	0.008	0.782

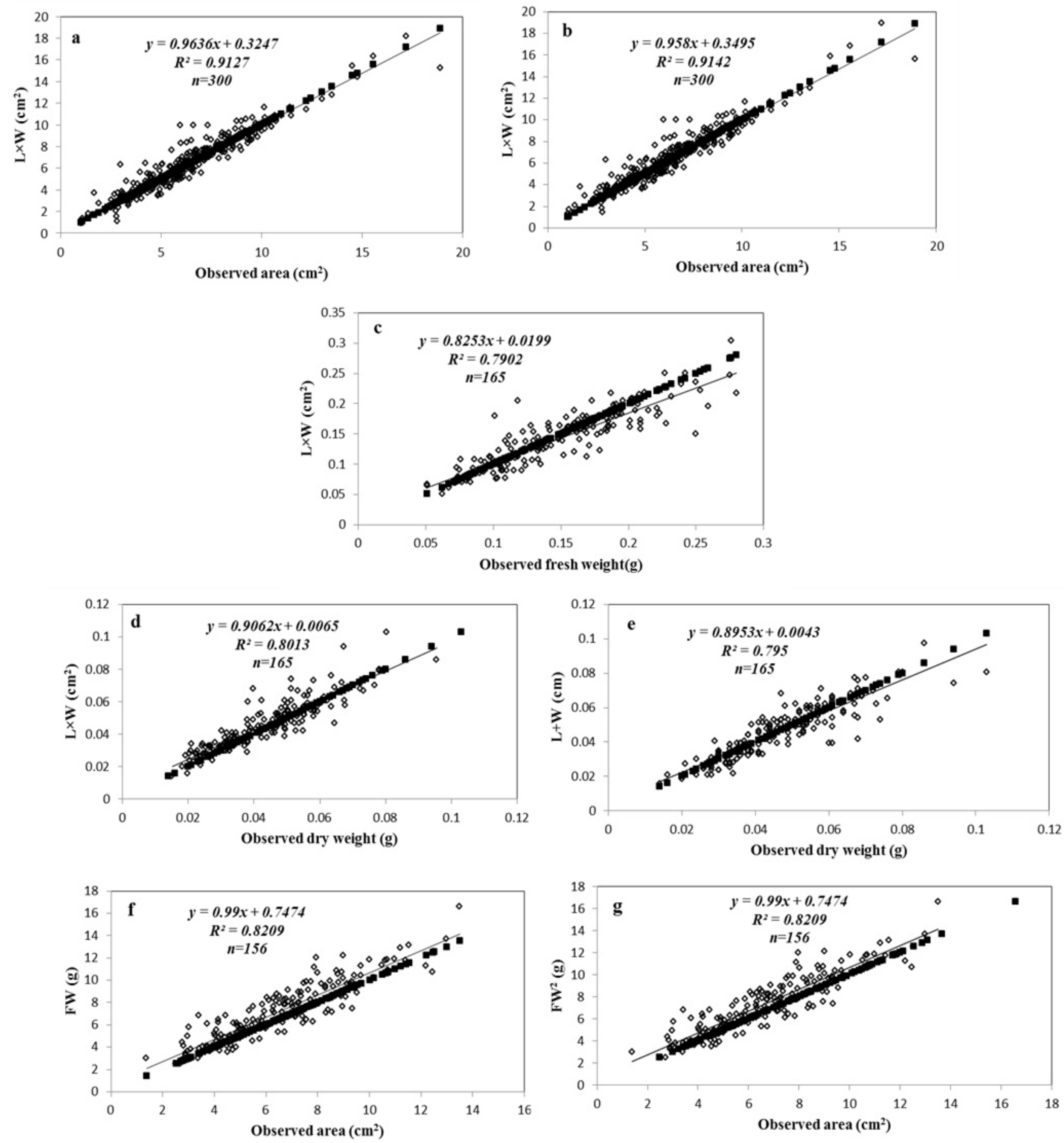

Fig. 3. Comparison of predicted and observed areas, fresh weight and dry weight of *Ficus benjamina* leaves using selected models. [*FW*-fresh weight; *L*-length; *W*-width].

Table 7. Slope (b) and intercept (a) values of the models used to estimate the *Ficus benjamina* (cv. Starlight) Leaf Area (*LA*) of single leaves from leaf fresh weight (*F*) and leaf dry weight (*D*) measurements.

Model number	Regression model	R^2	Bias	RMSE	RMAE	*CV*	*a*	b
1	$LA = 45.611F^{0.9798}$	0.850	0.0870	1.333	0.138	16.50	1.055	0.859
2	$LA = -280.42D^2 + 160.68D + 0.4444$	0.719	0.0007	1.700	2.890	21.04	2.274	0.719
3	$LA = 127.98D + 1.2646$	0.719	0.0003	1.707	0.195	21.12	2.291	0.716
4	$LA = -15.111(F+D)^2 + 41.797(F+D) - 0.3654$	0.834	0.0004	1.307	0.146	16.18	1.345	0.834
5	$LA = 34.465(F+D) + 0.4093$	0.832	-0.0004	1.314	0.147	16.26	1.358	0.832
6	$LA = 78.228(F{\times}D)^{0.4838}$	0.813	0.1120	1.362	0.150	16.87	1.213	0.836
7	$LA = -8041.8(F{\times}D)^2 + 608.8(F{\times}D) + 3.149$	0.811	0.0066	1.394	0.166	17.25	1.528	0.811
8	$LA = 45.611(F^2)^{0.4899}$	0.850	0.0870	1.331	0.138	16.48	1.055	0. 859
9	$LA = -67366(D^2)^2 + 1693.6(D^2) + 3.674$	0.704	-0.0004	1.734	0.208	21.53	2.389	0.704

LA, Leaf area; *F*, leaf fresh weight; *D*, leaf dry weight

Table 8. Validation of models for estimation of total leaf area *Ficus benjamina* cuttings.

Model number	R^2	Bias	RMSE	RMAE	*CV*	*a*	*b*
1	0.8209	-0.681	1.316	0.181	19.87	0.7474	0.99
2	0.8191	-0.635	1.219	0.177	18.40	1.5794	0.8573
3	0.8181	-0.624	1.212	0.172	18.30	1.7381	0.8319
4	0.8478	-0.727	1.245	0.176	18.80	0.8673	0.9788
5	0.8487	-0.720	1.225	0.175	18.50	0.9859	0.9598
6	0.8601	-0.540	1.093	0.151	16.50	0.7803	0.9637
7	0.8545	-0.665	1.159	0.174	17.50	1.1295	0.9298
8	0.8209	-0.681	1.316	0.181	19.87	0.7474	0.99
9	0.8066	-0.621	1.238	0.192	18.69	1.8534	0.8139

To estimate leaf area by measuring leaf fresh and dry weight, we obtained power functions viz., Eq. (8) & (1) using a fresh weight which had well relationships with *LA*, cleared in high R^2 (0.850), nearly lowest RMSE (1.331 & 1.333), lowest RMAE (0.138) and nearly lowest *CV* (16.48 & 16.50) values among the other equations (Table 7, Fig. 3: no. 6 & 7). Comparisons were made between measured versus calculated leaf area of other 300 leaves that were not involved in modeling set by using selected models. It was found that the Eq. (1) may be better than Eq. (8) to estimate leaf area using fresh weight measurement (Table 8, Fig. 3: no. 6 and 7).

4. Discussion

Several studies have been carried out to estimate leaf area by measuring leaf length and width (Robbins and Pharr, 1987; Gamiely *et al*., 1991; Montero *et al*., 2000; Williams III and Martinson, 2003). We found that regression equation were fitted using the length and the width of the leaves, the product of them and their squares as independent variables to estimate leaf area, fresh and dry weights. Leaf length or width exclusively did not offer a good variable to estimate leaf growth indices, and it is in similarity with Karimi *et al*., (2009) but indifference with Williams Iii and Martinson, (2003) and Cho *et al*., (2007) that declared a solitary variable of either leaf length or leaf width has a good correspondence with leaf area and or leaf weight.

Our research results indicated that the product of leaf length and width is a proper variable to verify *LA* and *FW* and both product and sum of *L* and *W* are suitable variables to determine *DW* using regression models. The variable with the highest explanatory capability was used to develop a general equation to predict *LA*, *FW* and *DW*. It was revealed that areas of this type of *Ficus* leaves are well correlated to the product of its length and width with high R^2 values. R^2 values for fresh weight (0.838) and dry weight (0.771) of leaves were less than the R^2 value of leaf area (0.950), as Cho *et al*., (2007) and Krimi *et al*., (2009) found and this was reasoned by Cho *et al*., (2007) that it is probably due to differences in specific leaf area. They stated that SPAD data are useful to determine leaf yield; but in this study, SPAD was not investigated.

There are lots of works which suggest calculation of leaf area from leaf dry weight data (Sharrett and Baker, 1985; Ma *et al*., 1992; Akram-Ghaderi and Soltani, 2007) but we found a reasonable relationship between leaf fresh weight (not dry weight) and leaf area. Power function described this relationship better than the other equation types.

Validation of selected models by independent data showed a strong conformity between predicted and measured data. According to these results, leaf length and width contribute to rapid, simple and non-destructive determination leaf area, leaf fresh and dry weight. Moreover, leaf fresh and dry weight could be used to estimate leaf area of *Ficus benjamina* (cv. Starlight). Further studies are required to evaluate these models or constructing new models for other cultivars of this ornamental plant.

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